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Global energy-mineral nexus by systems analysis approaches

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Abstract

After the Great East Japan Earthquake, Japanese energy policy strategies have been directed towards seeking more diversified energy options, especially fuel switching to gas, rapid introduction of renewable energy, and pushing towards a hydrogen economy. While a secure supply of energy, or energy security, is typically argued within the context of energy resources, little consideration for energy policy is given to mineral resources used in various energy technologies. Many studies have addressed the specific mineral elements in technologies by borrowing energy scenarios from authorities (e.g., The International Energy Agency (IEA) energy technology perspectives (ETP)). Some have applied empirical estimation models such as logistic functions for their future demand projections. In this study, we used our own resource balance models incorporating resources of energy, non-fuel minerals, biomass and food, to illustrate future consumption paths for non-fuel minerals (including scarce metals) as well as our own energy and climate policy scenarios. Our approach is complementary, not a substitute, offering more insights to existing studies on energy-mineral nexus approaches.

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renewable energy; energy resources; mineral resources; nexus; scenario; systems analysis

1. Introduction

Nexus approaches recently become popular for a variety of intersecting sectors - for example, the energy-biomass (food)-water nexus has been widely examined [1].The energy-mineral nexus has also recently gained attention, especially following the publication of reports on critical metals by the

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Department of Energy, United States of America (USDOE) [2] and by European Commission Joint Research Centre (JRC) [3].

Many studies (e.g. [4-9]) have addressed scarce (or critical) metals used in various energy technologies, such as wind power (WP), automobiles (for rare earth element (REE) used in magnets), fuel cells (platinum group metals), thin-film photovoltaics (PV, using elements such as Gallium, Indium), Lithium ion batteries (lithium), and other REE uses other than magnets. Renewable energy technologies are more metal intensive than current energy sources and a decarbonisation would increase demand for many materials [7]. For example, mining, manufacturing, and recycling industry gets increasingly tied together with the energy sector as the share of renewable energy increases [8,9]

In this paper, a systems modeling approach to energy-mineral-biomass linkages is presented; with some initial trials to understand order of magnitude of uncertainty in scarce metal requirements in energy and climate policy scenarios; and finally discussions on challenges of the energy-mineral nexus.

2. Outline of our modeling and analysis

Our global model balances demand and supply of resources for energy, minerals, biomass, and food formulated as dynamic linear programming over the time horizon of this century [10,11]. The model consists of production of resources, land use and land use changes, inter-regional transportation, energy conversion (power, liquid fuels, gas), production of materials (e.g, ferrous, non-ferrous (aluminum, copper, lead, zinc), and limestone), final demand, wood products, disposal of used products, and materials recycling. The model incorporates around 100 bottom-up detailed technology options used to meet the exogenously given demand scenarios to provide a consistent structure for supplying resources.

Three sub-models are linked together. In addition to wood and logs as fuel for biomass energy with carbon capture and storage (BECCS), biomass residues from various biomass and food processes and products are used as potential supply of biomass resources in the energy systems model. Electricity and heat consumed in the material model are also endogenously linked to the energy systems model. Fly-ash from pulverized coal-fired power plants in the energy systems model is endogenously linked to the Portland fly-ash cement process in the material model. Zinc is also used as steel coating, which is assumed to recovered as potential zinc source. Since relations between cumulative tonnage production and ore grade for copper, lead, and zinc are given, energy consumption increase by ore degradation as well as energy penalty by mineralogical barrier are also taken into consideration.

We originally set up two patters of energy (especially power) scenarios and two climate policy scenarios. One energy scenario is dominated by gas and renewable (denoted as Gas/Ren), while another is coal and nuclear (Coal/Nuc) can be introduced substantially. The scenario changes in computation can be executed by assuming ad-hoc cheap gas and uranium respectively in each energy scenario. We give common constraints in both scenarios for share of generation types; sum of PV, WP and ocean, coal power, gas power (allowed base operation), and bio+oil power is less than 20%, 30%, 40%, and 10%, respectively. The climate policy scenarios are business as usual (BAU) with no emission control of greenhouse gases (GHGs), and zero emissions in the latter half of this century by giving cumulative emissions of Wigley Richels Edmonds (WRE) [12] 350 ppm constraints over the computational time horizon (from 2010 to 2150).

In order to make rough estimation of critical metal requirements of WP and PV in the scenarios, we gave assumptions on plant availability, market share of CIGS type of PV, intensity use of the scarce minerals (Indium, Gallium, Niobium, Dysprosium) are given with uncertainty ranges referred from references [2,13].

3. Results

The figure illustrates uncertainty ranges of the four scarce minerals with power supply breakdowns under the two energy scenarios in the zero emissions scenario. Ranges of metal requirements for Elysium and Gallium in PV are from minimum share with minimum intensity of use, to both maxim. Since share and intensity ranges 5 and 6 time higher each, the uncertainty ranges wider than that of PV in capacity basis (roughly 15 times) when compared with the two energy scenarios. The metal requirements for WP are almost comparable because of its produced power in the both energy scenarios.

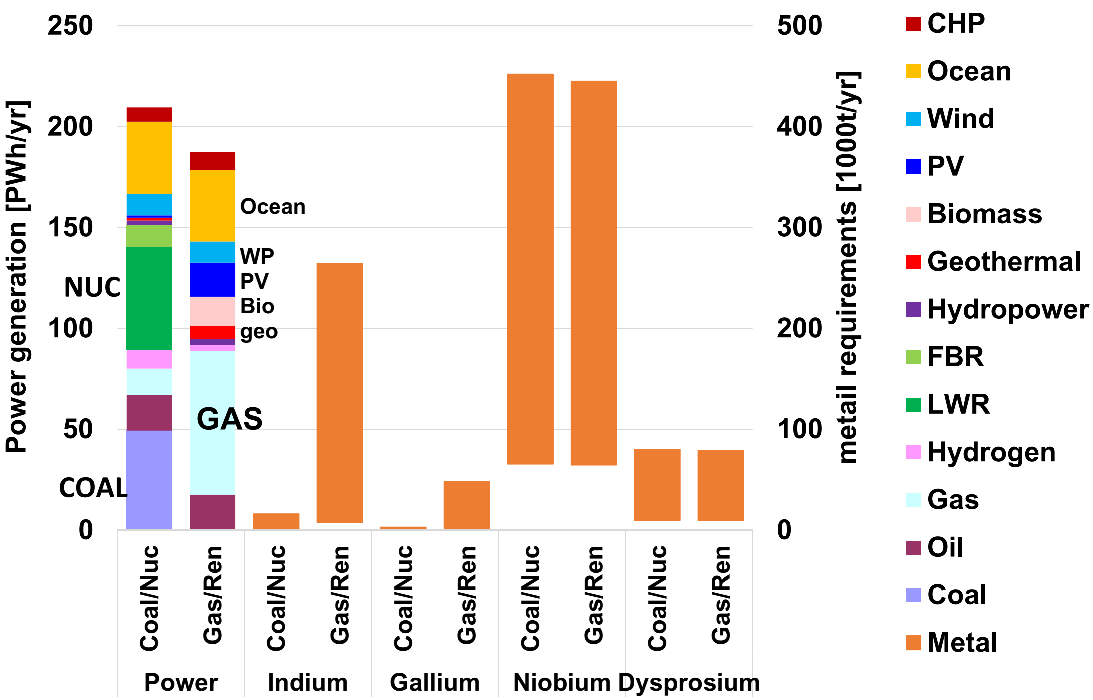

Fig. 1. Power breakdowns and metal requirements in both energy scenarios under zero emissions scenario

4. Discussions and the way forward

This preliminary trial includes uncertainty on i) energy choice or energy resource development, ii) climate policy agreement (i.e., target setting and consensus on emissions reductions), and iii) share of various types of technology (e.g., CIGS and others in PV) and intensity of use of metals. Although this is just a rough estimation, metal requirement seems to be much wider uncertainty ranges than energy scenarios, but lower than shadow price of carbon (ranges in roughly 100 times) [14]. We had excluded uncertainty on mineralogical aspects whether such a large production of critical or scarce minerals in one year, which may sure be another challenges. Even such a preliminary exercise tells us that energy-mineral nexus requires us to understand various interactions among such as technology, society, mineralogy, policy and so on [15]. Great effort to reduce the uncertainty ranges and to include technologies are required

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